Structural defects due to growth interruptions in ZnSe-based heterostructures

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Heterostructures based on wide bandgap II–VI compounds and their alloys are currently under intensive studies aiming at fabrication of long-living green laser diodes. After the first demonstration of the room temperature laser many efforts have been made to improve the characteristics and quality of the devices. It is generally known that the main reason of degradation are both extended (misfit dislocations and stacking faults (SFs)) and point defects in the active region of a laser structure [1, 2].

GaAs is a commonly used substrate for ZnSe-based semiconductors growth due to its fairly low lattice mismatch to ZnSe (0.27%). The origin of SFs and dislocations is associated with the heterovalent nucleation of ZnSe on GaAs. Therefore, the properties of the heterointerface between a GaAs substrate and ZnSe are of great importance for the structural quality of the layers. It has been shown that an initial growth stage and the growth conditions of the first few ZnSe monolayers are dominant factors affecting the layer quality and determining the dislocation and SF density [3]. Studies of the initial nucleation of ZnSe on GaAs substrates indicate that stoichiometry of GaAs surface before growth can change the initial growth mode from a 2-dimensional (2D) layer-by-layer to a 3D-island one. The SF density is significantly higher for the films grown on Ga-rich GaAs surfaces in comparison with those on As-stabilized one [1]. The use of a high quality GaAs buffer layer results in a noticeable decrease in the extended defect density [4].

The defects may also arise during the growth process, initiated either by technological stops performed for calibration of the fluxes by ion gauge after a ZnSe-buffer growth or by interruptions at guide/cladding interfaces for necessary variation of substrate temperature or flux intensities. Note that the non-interrupted shutter-operation MBE technique proposed in [5] allows us to produce the structure with improved optical and structural qualities. It has been also suggested that the stands form a specific homo-interface, where the defect formation is simplified, meanwhile this assumption had no experimental confirmation until now. Another serious problem in II–VI growth is penetration of the defects, damaging active region and adjacent layers. To enhance the heterostructure stability much attention has been paid to design and growth of alternately-strained superlattices (SLs) [6]. However, the ability of such SLs to stop defects has not been directly documented for II–VI's.

In this paper we focus on the growth-interruption-induced defects formation as well as on their extinction by a SL. The samples studied were grown by molecular beam epitaxy on GaAs (100) substrates either with or without GaAs buffer layer. All structures were grown on As-stabilised GaAs surface exposed to Zn for 2 minutes prior to the growth of a 20 nm thick ZnSe buffer. The growth conditions and composition control for these heterostructures have been reported elsewhere [7]. To study the defects formation on the interrupted interfaces, the simplest heterostructures were used, containing 50 nm of ZnSe followed by a thin CdSe insertion, capped finally by 20 nm of ZnSe. The total ZnSe thickness was chosen to be less than the critical one. After 20 nm growth of the ZnSe buffer layer the growth interruption took place to calibrate the fluxes with an ion gauge
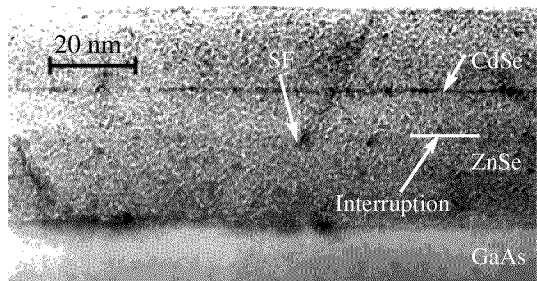
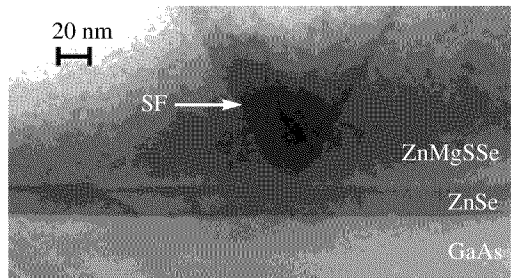**Fig. 1.** TEM cross-sectional image of a ZnSe/CdSe/ZnSe structure.

Fig. 2. TEM cross-sectional image taken near a ZnSe/ZnMgSSe interface.

placed in front of the wafer surface at $\sim$ 0.5 cm. A typical laser structure was used to study capability of SLs to quench defects. The structure consists of a 20 nm ZnSe buffer layer, a 0.5 μm thick ZnMgSSe bottom cladding layer, a 0.2 μm ZnSSe/(Zn,Cd)Se short-period SL region centered with a 7 nm wide (Zn,Cd)Se QW, and finally a 0.1 μm ZnMgSSe top cladding layer protected by a 5 nm ZnSe cap. The samples were studied by cross-sectional transmission electron microscopy (TEM) using Philips EM420 electron microscope.

TEM cross-sectional image taken from a ZnSe/CdSe/ZnSe structure is presented in Fig. 1. The structure was grown with an interruption for the flux calibration. The closest to the surface line is a 0.5 monolayer thick CdSe insertion serving as a checkpoint. Below the CdSe layer an additional interface is visible, exactly matching the position of the ZnSe growth interruption. The SF (marked by an arrow) is clearly seen in the figure, originating just from the homo-ZnSe/ZnSe interface and crossing the CdSe insertion. Figure 2 shows a TEM cross-sectional image taken near a ZnSe/ZnMgSSe interface in a sample, characterized by the layer-by-layer growth mode of ZnSe/GaAs on the As-stabilized GaAs buffer. The film is perfectly coherent with the GaAs surface. However, the growth interruption for the flux calibration took place during the epitaxy at the ZnSe/ZnMgSSe interface. The interface is seen in Fig. 2 as a thin dark stripe and the stacking fault nucleates just in this place of the structure.

Figure 3 presents a cross-sectional image of the laser structure with an alternately-strained SL waveguide. The 2D initial growth mode of this structure has provided the low SF density at the ZnSe/GaAs interface, while the growth interruption for fluxes calibration performed at the ZnSe/ZnMgSSe interface results in the SF nucleation. However, the SFs starting from the ZnSe/ZnMgSSe interface are completely suppressed by the SL, which demonstrates a protective ability of the strained II–VI SLs against penetration of the extended defects into the laser active region.
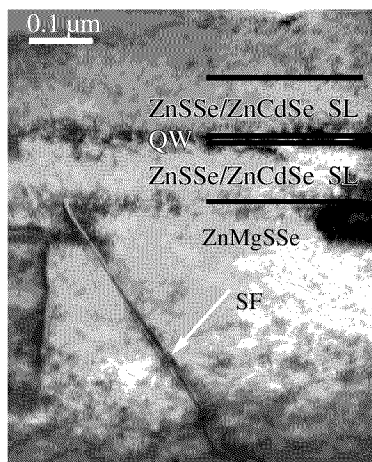
Fig. 3. TEM cross-sectional image of the laser structure with alternately-strained SL waveguide.

In summary, it has been shown that the growth interruption performed for calibration of VI–II flux ratio leads to the additional strain contrast in cross-sectional TEM images. Furthermore, this strain seems to be the driven force for the formation of extended defects immediately at the interruption interface. On the other hand, the developed alternately-strained SLs allow one to enhance the activation energy of the development and propagation of extended defects and protect the laser active region from the defects penetration. This findings, while being qualitative, are important for further decrease of the defects density in ZnSe-based laser structures.

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